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Fabrication of Electrostrictive Ceramic Rings for Navy Sonar Transducers

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Executive Summary

The higher order electromechanical coupling "electrostriction" has been proposed as an alternative to the piezoelectric phenomena commonly employed for Navy-type sonar transducers. Based on the results of the parent program, "Relaxor Ferroelectrics for Electrostrictive Transducers" (N00014-90-J-4077), and the continuation program, "Micro-Mechanics of Electrostrictors for Sonar Transducers," three compositions of electrostrictive ceramics were fabricated into large rings and delivered to Dr. Robert Ting of the Underwater Sound Ref. Division, Naval Research Laboratory in Orlando, Florida.

Specific compositions (3) were selected based on the given criteria:

- Large E-field induced strain > 0.03%
- Operating temperature range 0-30°C
- Minimal strain–E-field hysteresis (< 10%)

The large rings (4 each) were fabricated with the following dimensions: O.D. = 2.000 ± 0.01 in. (50.8 mm), wall thickness = 0.250 ± 0.010 in. (6.35 mm), and thickness = 0.430 ± 0.002 (10.9 mm). The four rings were electroded (fired on silver) and to be stacked into an assembly for standard testing and evaluation at NRL in Orlando, Florida.

Tranducer Fabrication and Testing

A. Compositional Selection

Three relaxor ferroelectric compositions were selected for evaluation as practical Navy transducers as follows:

(1) 0.95 $Pb(Mg_{1/3}Nb_{2/3})O3$-0.05 $PbTiO_3$ [95/5 PMN]

(2) 0.90 $Pb(Mg_{1/3}Nb_{2/3})O3$-0.10 $PbTiO_3$ + 1 mole % La [PLMNT] 1/90/10

(3) 0.85 $Pb(Mg_{1/3}Nb_{2/3})O3$-0.15 $PbTiO_3$ + 2 mole % La [PLMNT] 2/85/15

B. Powder Fabrication /Synthesis

Four to five kilogram batches of the above formulations were prepared as detailed in the parent program. Large quantities were necessary for the production of large ceramic rings. XRD analysis, Figure 1, revealed nearly single phase perovskite at calcination temperature of only

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700°C. Sample disks (~ 1/cm diameter and 1 mm thick) were fabricated and tested to ensure the quality of the powder lots.

As presented in Figure 2, the dielectric temperature curve for a PLMNT 1/90/10 disk was found to be representative of a relaxor ferroelectric chemically engineered for operation from 0°–30°C. Representative strain–E-field and strain-polarization curves for the relaxor materials are given in Figures 3–5. As presented (Figure 4), little hysteresis was observed with strain levels significantly larger than the required level of 0.03%. The classic quadratic strain-polarization behavior is shown in Figure 5 for PMNT 95/5.

C. Electrostrictive Ceramic Ring Fabrication

Powders prepared above were granulated and pressed into large cylinders. Subsequent to binder burnout and densifications, the cylinders were machined (Piezo Kinetics, Inc.) to the desired dimensions as given in Figure 6. Upon machining, the samples were electroded using fired-on silver; at ~ 550°C for one-half hour. Unlike that found for PZT-based ceramics, the role of the electrode interface in high dielectric constant materials is a major concern.

D. Electrostrictive Ring Testing

Owing to the relatively large thickness of the rings, 10.9 mm, and the voltage limitation of 4,000 volts for the Sawyer Tower system, only strain-polarization loops up to 4 kV/cm could be achieved. At these levels, no hysteresis was noted. Ten thousand volts (10,000 V) were applied to each ring to ensure electrical integrity.

E. Sample Delivery

At least four (4) sample rings of each composition were delivered to Dr. Robert Ting at NRL, Orlando, Florida, for transducer qualification and testing.

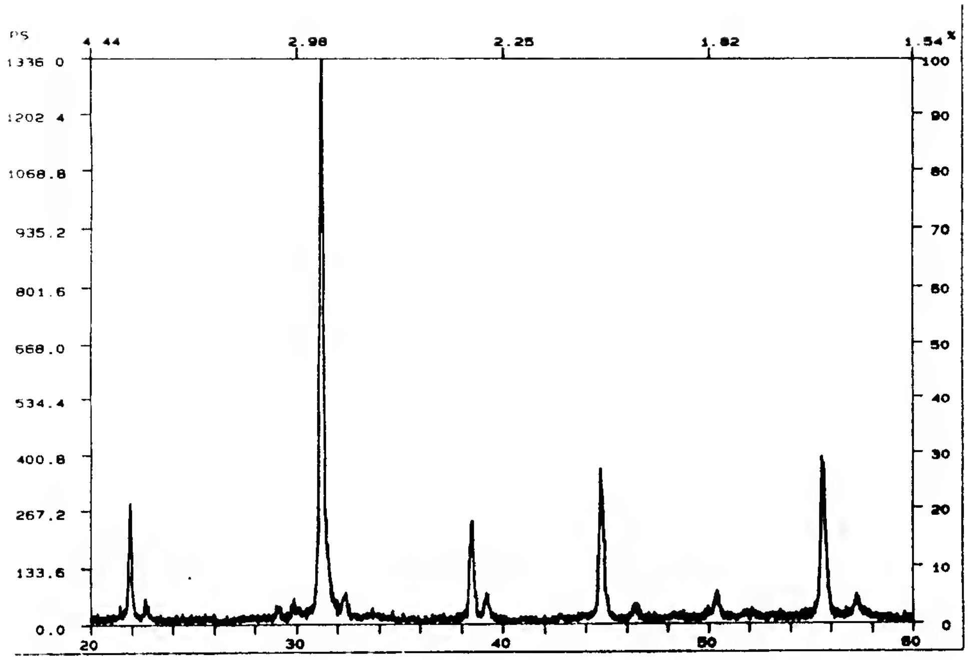


Figure 1. XRD (powder x-ray diffraction) pattern for the 2/85/15 relaxor ferroelectric calcined at 700°C. (Large batch lot 4 kg.)

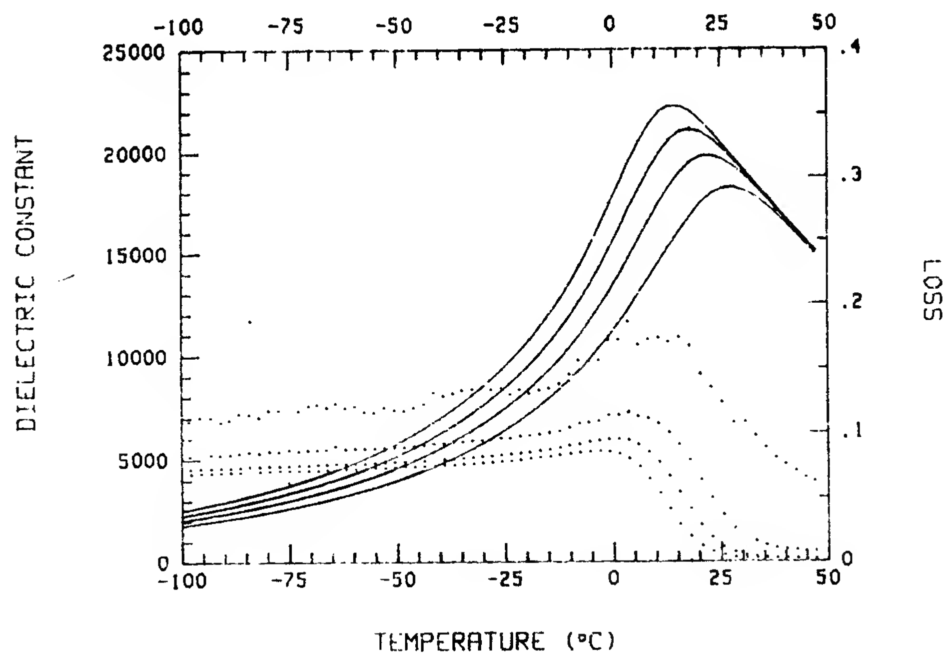
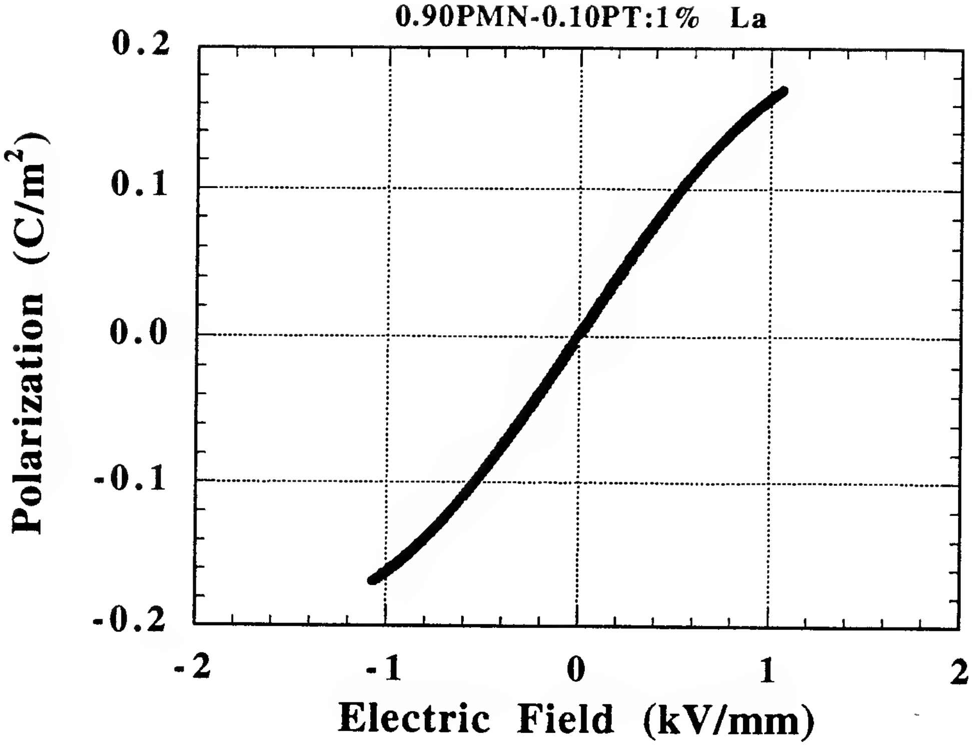


Figure 2. Representative dielectric (K and loss) as a function of temperature and frequency (100 Hz, 1 kHz, 10 kHz,and 100 kHz, left to right) for a 1/90/10 ceramic fired at 1250°C.



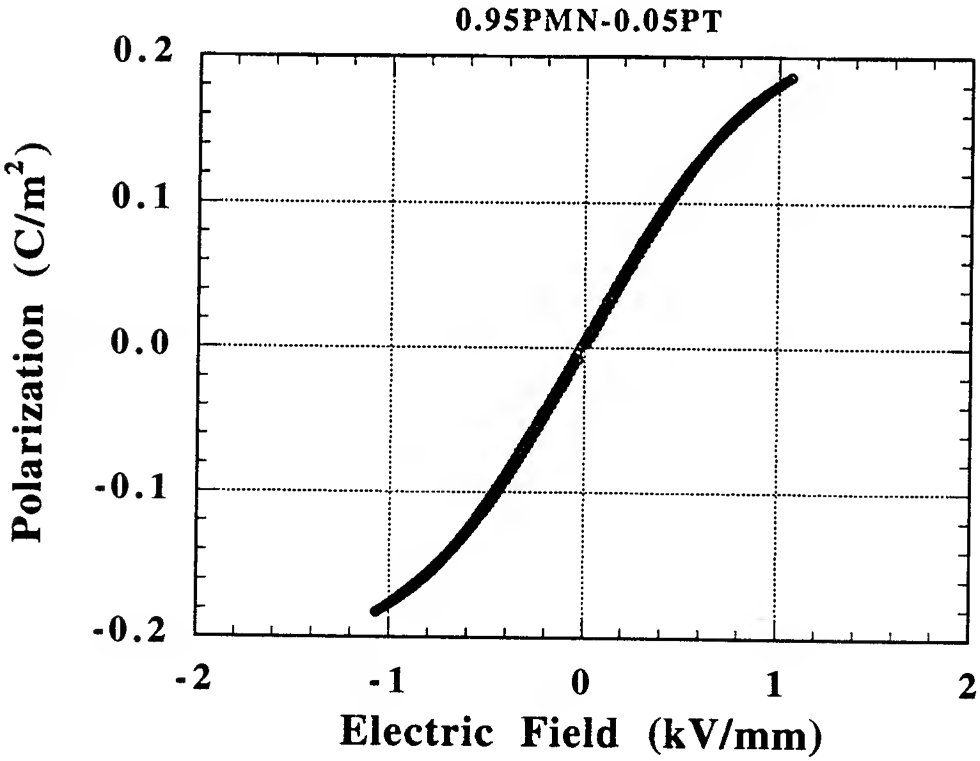


Figure 3. Polarization–E-field behavior for 90/10/1 and 95/5 PMN relaxor ferroelectrics showing slim-loop behavior and minimal hysteresis.

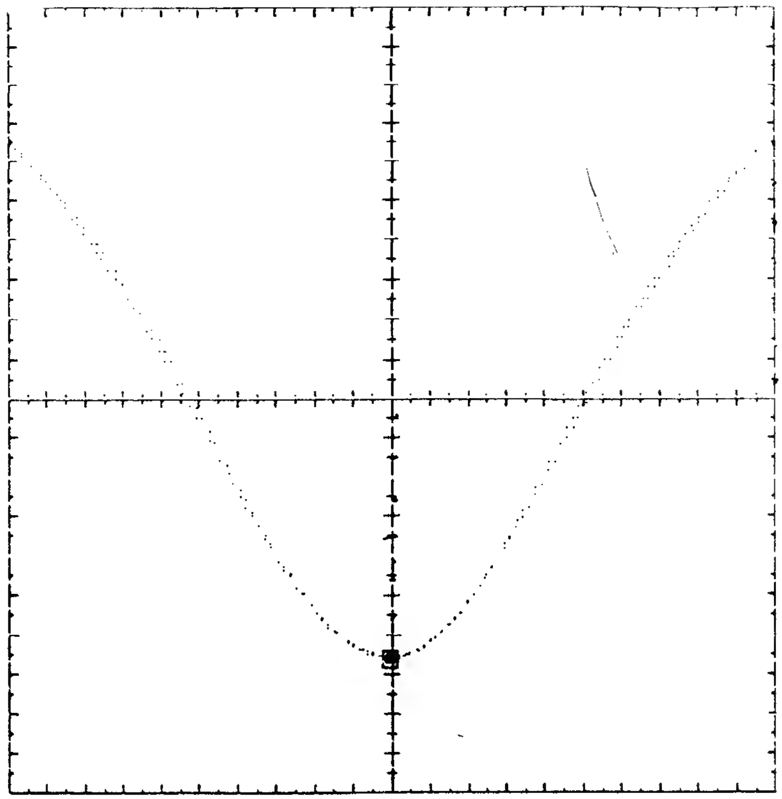


Figure 4. Strain (longitudinal) vs. E-field for a 2/85/15 PLMNT composition exhibiting minimal hysteresis. Y-axis - strain - 0.08% @ 20 kV/cm
X-axis - E-field - 20 kV/cm full scale

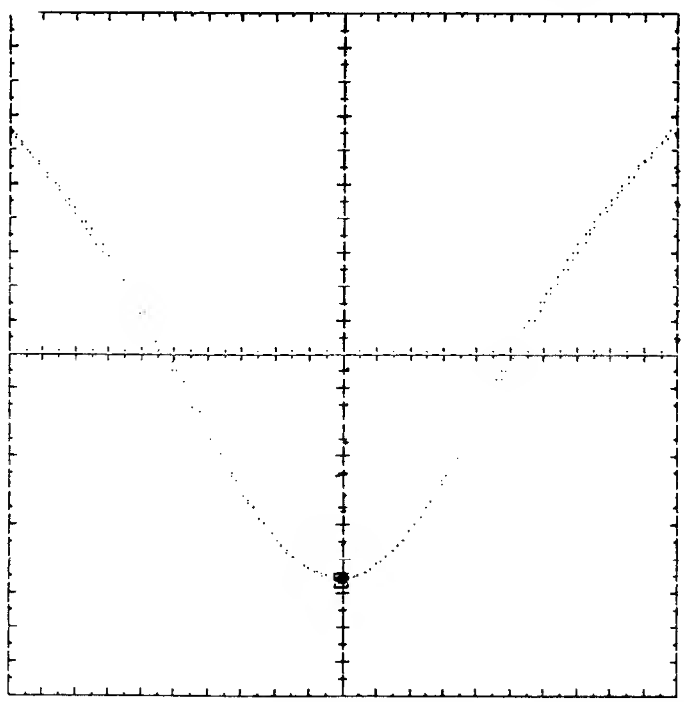


Figure 5. Strain (longitudinal) vs. polarization for a 95/5 PMNT ceramic exhibiting classic quadratic electrostrictive behavior.

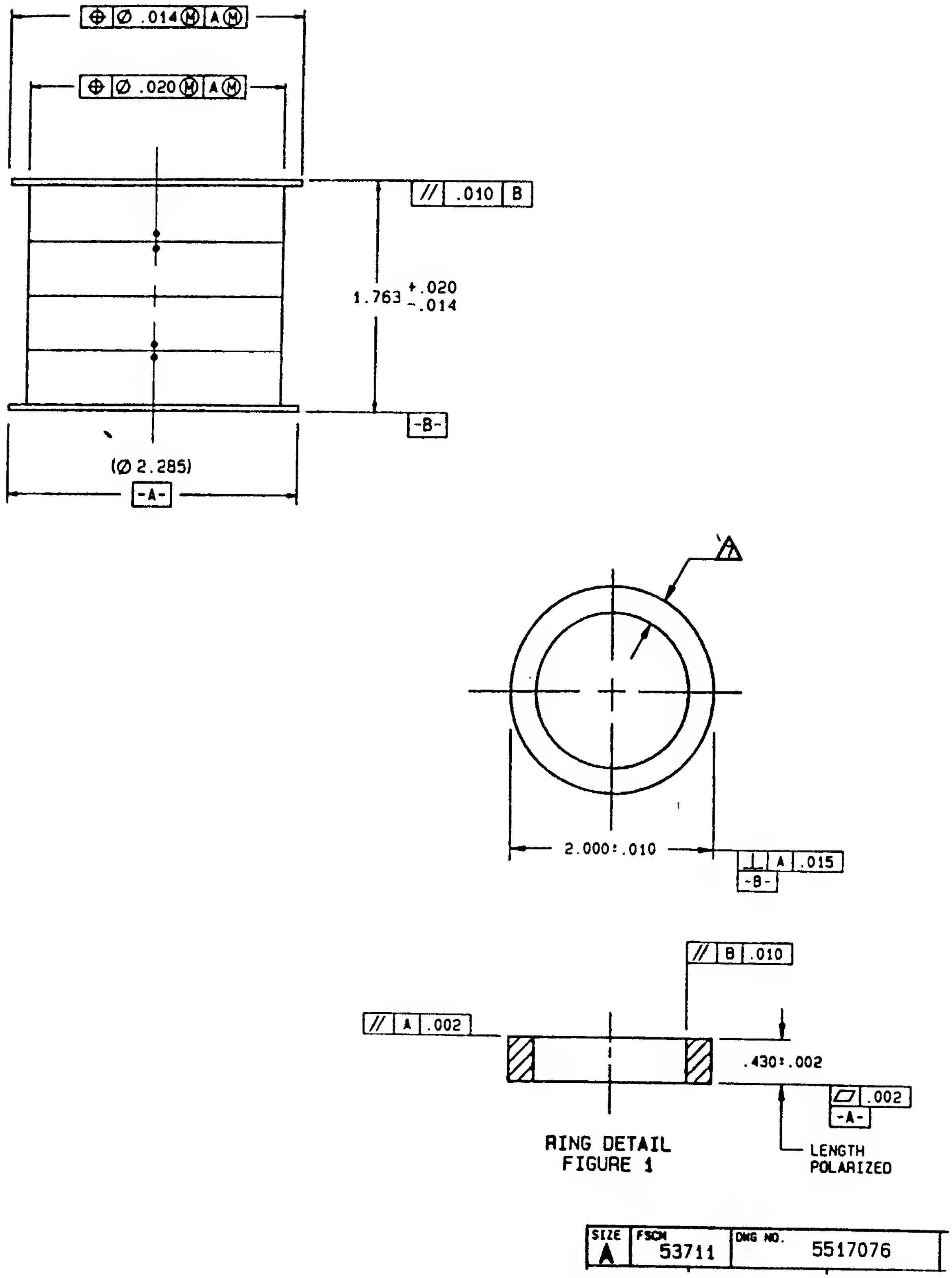


Figure 6. Schematic drawing of the individual and stacked ring assembly for a Navy sonar transducer.